Defense Technical Information Center Compilation Part Notice

ADP014076

TITLE: Wiring System Diagnostic Techniques for Legacy Aircraft

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

This paper is part of the following report:

TITLE: Ageing Mechanisms and Control. Specialists' Meeting on Life Management Techniques for Ageing Air Vehicles [Les mecanismes vieillissants et le controle] [Reunions des specialistes des techniques de gestion du cycle de vie pour vehicules aeriens vieillissants]

To order the complete compilation report, use: ADA415672

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP014058 thru ADP014091

Wiring System Diagnostic Techniques for Legacy Aircraft

David H. Johnson
Materials Engineer for Electronic Materials Evaluation
Air Force Research Laboratory, AFRL/MLSA, 2179 12th St., WPAFB, OH 45433-7718, USA
Ph. 937.656.9163, Fax 937.656.4600, Email: David.Johnson2@wpafb.af.mil

Edward L. White
Materials Engineer for Electronic Materials Evaluation
Air Force Research Laboratory, AFRL/MLSA, 2179 12th St., WPAFB, OH 45433-7718, USA
Ph. 937.656.9162, Fax 937.656-9147, Email: Eddie.White@wpafb.af.mil

Joseph J. D'Angelo, Jr.
Deputy Director of Manufacturing Operations
GRC International Inc., 2940 Presidential Dr., Suite 390, Fairborn, OH 45324, USA
Ph. 937.429.7773, Fax 937.429.7769, Email: jdangelo@grci.com

Dwayne Dicks
Manager for Technical Services,
GRC International Inc., 2940 Presidential Dr., Suite 390, Fairborn, OH 45324, USA
Ph. 937.429.7773, Fax 937.429.7769, Email: ddicks@grci.com

Adam L. Decker
Senior Technical Services Specialist
GRC International Inc, 2940 Presidential Dr., Suite 390, Fairborn, OH 45324, USA
Ph. 937.429.7773, Fax 937.429.7769, Email: adecker@grci.com

Abstract

As aircraft continue to age, managing the overall wiring system is becoming an important issue. Over time, the accumulation of stresses from the operational environment, installation, and maintenance can induce wiring failures. In both design and maintenance, wiring is usually treated more as a commodity than a subsystem. A systematic process for managing wiring is only now just emerging. A major challenge is the development of wiring diagnostic equipment. The diagnosing and repairing of wiring failures can cause extensive downtimes for aircraft. Interconnection failures cannot be easily identified since most test equipment is designed to locate failures in avionics and not the connector or wiring. Additionally, wiring failures tend to be intermittent in nature and can take considerable time to isolate. Significant reduction in maintenance costs can occur by moving from unscheduled maintenance to a scheduled, preventative, or opportunistic maintenance philosophy based on the ability to isolate and repair degraded electrical systems. This paper will address the wiring system maintenance issues and concerns, field maintenance diagnostic requirements (needs), and compare available diagnostic tools in terms of utility, ease of use, and setup time. It will also address efforts currently being accomplished to modify/adapt commercial off the shelf testers to meet the requirements that will enable the United States Air Force to more effectively manage wiring as an aging subsystem.

Paper presented at the RTO AVT Specialists' Meeting on "Life Management Techniques for Ageing Air Vehicles", held in Manchester, United Kingdom, 8-11 October 2001, and published in RTO-MP-079(II).

Introduction

Aging wiring has become both a high interest and high cost item for the Air Force maintenance community. As the average age of the Air Force fleet continues to rise, wiring problems are becoming an increasing concern. Yet the term, aging wiring, is not well understood by the aerospace community. For the purposes of this paper, aged wiring is defined as wire exhibiting degraded performance due to accumulated damage from long-term exposure to chemical, thermal, electrical, and mechanical stresses. The operational environment, installation, and maintenance practices often induce these stresses. Diagnosing and repairing wiring faults can cause extensive downtimes for aircraft. In both design and maintenance, wiring is usually treated more as a commodity than a subsystem. Most troubleshooting systems, including aircraft built-in-test and automated testers for line replaceable units (LRUs), indicate failures occur in the black boxes. Interconnection failures cannot be identified. Additionally, wiring failures tend to be intermittent in nature and can take considerable time to isolate. Wire modifications and repairs in the field can also be difficult to verify since field evaluation systems are not effective. The time maintenance personnel spend diagnosing and repairing faulty wiring is becoming a leading cause of aircraft downtime. Current maintenance procedures do not adequately address wiring as a system. Visual inspection of individual wires in a bundle or connector is not practical because as wire ages it becomes stiff, and dismantling the bundle or connector may introduce collateral damage resulting in safety hazards. Without providing maintenance personnel improved diagnostic equipment, the costs associated with wiring failures will continue to increase. Air Force aircraft maintenance occurs in one of three levels: phase, field, and depot. Depot activities are focused towards maintenance modifications. Phase-level activities are focused towards scheduled maintenance inspections. Field-level maintenance activities are more reactive in nature with the objective to get the aircraft mission capable. There are no scheduled wiring inspections in any of these maintenance actions. Field-level maintenance is the area with the greatest need for an advanced testing system. Currently, a reactive approach is taken where the maintainers look at the wiring only after LRUs have been removed and replaced several times and the problem still exists. After performing a visual inspection with a flashlight and mirror, the most commonly used piece of equipment is the multimeter. This piece of equipment is preferred because it is easy to use, portable, and easy to interpret the results. Drawbacks to using the multimeter are that it is a time consuming process to try and isolate the fault pin-by-pin; its use requires two people to allow for connection at both ends; there is no data archiving or retrieving capability; and it is an extensive process to physically locate faults. During phase-level maintenance, the opportunity exists to perform a comprehensive inspection of wiring if needed. At this level, the aircraft is de-paneled at the beginning of the process which allows the maintainer greater access to the wiring. The aircraft is also parked inside a facility, allowing the use of any type of test equipment. Maintenance stands are available next to the aircraft, allowing the use of heavier equipment and decreasing the need to use ruggedized equipment. By collecting and archiving wiring data, incipient faults can be identified and corrected before they impact aircraft readiness in the field. Significant reduction in maintenance costs can occur only if the Air Force moves from unscheduled maintenance (fix it when it breaks) to a scheduled, preventative, or opportunistic maintenance philosophy based on the ability to isolate and repair serious degradation (integrity verification).

Background

The need for aircraft wire diagnostic equipment has become apparent through findings of recent mishap investigations, as well as, surveys of USAF maintenance personnel. The surveys identified a need to improve the efficiency of diagnosing, locating, and repairing damaged and

degraded aircraft wiring, and a desire to track degradation trends. The investigation of the TWA Flight 800 fuel tank explosion, which caused the loss of the aircraft and 230 passengers and crew onboard, brought to light damaged and degraded wiring. The National Transportation Safety Board (NTSB) identified wire damage as part of the probable cause. Following this mishap, the Federal Aviation Administration (FAA) initiated a study of the condition of aged aircraft wiring under the guidance of the Air Transport Systems Rulemaking Advisory Committee (ATSRAC). The intrusive inspection phase of the ATSRAC study evaluated the condition of wiring on five different recently retired commercial aircraft models (A100, L1011, B747, DC-9, DC 10), each with over 20 years of service. The inspections involved three tasks: 1) detailed visual inspection with or without invasive follow-up, 2) nondestructive testing (NDT), and 3) laboratory analysis. Invasive follow-up meant spreading out the wire in wire bundles to allow evaluation of the condition of the interior wires and more complete evaluation of wires at the surface of bundles, sometimes with magnification.

In general, the visual inspections done during the intrusive phase of the ATSRAC study were more detailed than the general visual inspection procedures typically followed as a part of routine aircraft maintenance. Nondestructive testing to find insulation damage exposing the core conductor, high resistance, and conductor shorts and opens was done aboard the aircraft before wire bundle samples were removed for laboratory analysis. After the bundles arrived in the laboratory for detailed analysis of individual wires, they were again tested for insulation damage exposing the core conductor. It was expected that the very close, detailed inspections of the study would find most all defects in the sample bundles. The purpose of the NDT was to verify all defects had been identified during visual inspection, and to ensure the process of removing the bundle samples from the aircraft had not induced new damage. NDT done before the bundles were removed from the aircraft and follow-on laboratory procedures, however, found a significant number of defects that had gone undetected using these very rigorous visual inspection techniques. This is not an unexpected result given the findings of many studies done to evaluate the effectiveness of visual inspection in many different industries. Visual inspection has generally been found to be the least effective means of finding defects when compared with automated or instrumented inspection techniques.

Another concern about the use of general visual inspection as the primary wire management tool was the large amount of contamination on the wiring observed during the intrusive phase of the ATSRAC study. The accumulation had obviously taken place over a long period. The debris (e.g., lint, corrosion prevention compounds, drill chips from structural repairs, metallic shavings, coffee and other liquids, etc.), on/in many wire bundles in each of the study aircraft was so extensive that these bundles could not be seen; much less visually inspected adequately. There is apparently no requirement for aircraft wire to be cleaned prior to general visual inspection (GVI), or as a routine maintenance procedure.

As previously stated, general visual inspection is the only technique now used to monitor the condition of both commercial and military aircraft wiring on a continuing basis and to manage aging mechanisms and damage arising from normal operation and maintenance. Since substantially more damage sites were found using NDT and laboratory procedures during the ATSRAC study than had been identified using close visual inspection, it can be assumed that many wiring defects go undetected during normal maintenance operations. These are typically found only after system failures or very noticeable damage to a wire bundle, such as insulation charring, smoke, or electrical fire.

The results of the intrusive inspection are reported in the Transport Aircraft Intrusive Inspection Project Final Report (An Analysis Of The Wire Installations Of Six Decommissioned Aircraft) dated December 29, 2000 (Prepared by The Intrusive Inspection Working Group,

Christopher Smith, Chairman). This report is available from the FAA web site. The data in the Intrusive Inspection Final Report (if not the conclusions and recommendations), as well as, data related to the effectiveness of visual inspection, and participation in the intrusive inspection process clearly indicates visual inspection is not able to identify many types of damage and degradation. Some examples of what may be visually undetectable are: damage or degradation hidden inside wire bundles; high resistance connections (connectors, splices, terminal blocks, nicked conductors/broken strands, etc.) and excessive current density in high energy circuit paths until insulation is visibly charred or a fire has ignited; damage and degradation hidden under accumulated lint and other contaminants commonly observed on all six aircraft studied; damage inside protective wrap materials, conduit, or in inaccessible zones; small cracks and other insulation breaches at arms length without magnification.

Analysis of maintenance data and surveys of maintenance personnel indicate that wire failures, especially intermittent failures, often cause good boxes to be repeatedly pulled and sent for testing and repair at great expense before wiring is considered as the possible cause. Once wiring is identified as the problem, finding the location of the open, short or high resistance is also very time consuming and difficult. The consequences are higher cost of ownership and reduced mission readiness.

For the reasons sighted above, the need for wire diagnostic equipment is clearly indicated. It is necessary for more effective management of aging mechanisms, to allow more efficient diagnostics and repair of system failures caused by wiring, and to reduce the number of events and amount of damage done when defects cause failures resulting in charring, smoke, and fire. If safety is to be improved, inspection techniques must be able to identify the precursors before defects become visually obvious by having already caused charring, smoke, and/or electrical fires.

The ideal set of diagnostic equipment would be capable of data storage and analysis capabilities sufficient to allow trend analysis and be able to identify the following:

- Open circuits and measure where along a signal path the break occurred
- High resistance interconnects (e.g., splices, connector pins, terminal blocks) as they develop and allow intervention before I^2R heating causes insulation to, or a fire ignited
- Non-linear propagation characteristics within connectors and coaxial cable, which cause sensitivity to RF interference and/or heating of transmission lines
- The distance to conductor nicks, cracks, and broken strands before current density causes heating sufficient to degrade insulation, or alter signal propagation characteristics
- Hard and intermittent shorts to other power feeders or signal paths, and to structure and measure the distance to the defect area.
- Small cracks through to the core conductor having the potential to allow stray voltage and current paths wire-to-wire and wire-to-structure, when moisture or contaminant intrudes into wire bundles
- The presence of chafed insulation before the insulation is completely worn away allowing a wire-to-wire or wire-to-structure short.
- RF signal paths with impedance mismatches, high VSWR, and other undesirable signal propagation characteristics
- Shielding and grounding faults and faults in as well as twisted pairs which make sensitive signal paths susceptible to EMI, or to radiate energy which causes EMI problems in adjacent signal paths
- Points in wiring where high voltage corona effects and arcing may occur at altitude

Some of these capabilities already exist and require only a simple instrument like an ohmmeter or a multimeter to identify the existence of the defect. These instruments however, sometimes do not identify the location of a defect along a circuit path. Other techniques such as a standing wave reflectometry (SWR) meter, or time domain reflectometry (TDR) meter must be added to ascertain the anomaly location. Some of the defects above, such as chafing and insulation cracking, which may or may not have penetrated to the core conductor, are much more difficult to identify. Significant development efforts will be required to arrive at test equipment that can be operated by a maintainer of limited experience, require little set up time, operate under adverse work conditions, and able to identify difficult to see degradation and defects, especially in inaccessible zones or within heavily contaminated bundles.

The ultimate goal is to detect high-risk conditions before charring, smoke, electrical fire, arc tracking, or the failure of attached avionics or electromechanical devices can occur. Using present visual inspection techniques often requires these high-risk events to occur before the underlying defect is detectable. Although aircrews are usually able to cope with various equipment/system failures, these types of events, however, do have the potential to cause substantial damage and can lead to an aircraft accident.

Wire Integrity Tester Evaluation Plan

The objective of the Air Force program with GRCI, entitled Improvement of Wire System Integrity for Legacy Aircraft, is to procure wire system testers in both bench top (wire analyzers) and handheld configurations, evaluate them in the laboratory on a test bed, and optimize them for evaluating wire system integrity. The foci of the program are on defining requirements for evaluating wire test systems; identifying actual aircraft wire bundles for evaluation; establishing a wire system integrity test set evaluation test bed; and analyzing, evaluating, developing, and procuring specific wire system integrity test systems for optimization and feasibility demonstrations. The ultimate goal of the program is to transfer and install the wire integrity test systems at a field location as a system that can be used to locate wiring system anomalies and maintain wiring system integrity.

Background Study

One of the objectives of the lead-in project ("Wiring Integrity Analysis of Air Force Weapon Systems", AMTFD D064) was to evaluate aircraft wiring, document existing maintenance operations and conduct interviews with actual maintainers to determine field needs for wiring diagnostic tools. To achieve the overall objective, site visits were made to identify types of wire system faults that exist and to identify the types of tools and techniques needed to detect the faults. The field team was made up of AFRL and GRCI personnel who documented the current maintenance wire integrity testing practices. Areas of interest included techniques, equipment, documentation, data analysis, reporting, and corrective actions. Site surveys were used to gather information on maintenance operations and diagnostic test equipment requirements. The wire integrity team, GRCI and AFRL/MLSA, conducted site visits to Air Force Air Logistics Centers, and Air National Guard units. The aircraft reviewed included fighter and transport aircraft. The purpose of these visits was to identify potential wiring issues, and to engage in discussions with maintenance personnel. Topics included the usefulness of a wire integrity test system as a diagnostic tool and the benefit of test systems in the identification and resolution of wire anomalies. A major conclusion is that current visual inspection methods and hand-held tools are inadequate to identify most wiring problems. These findings and conclusions were consistent for all the types of aircraft evaluated. The input from the maintainers will be invaluable and directly used in providing a requirements list to the tester manufacturers. The

following sections provide a summary of the findings that are applicable to this study for fighter and wide body aircraft:

Maintenance Issues Identified

Most of the maintenance personnel that were interviewed welcomed the idea of a new tester that would make their jobs easier. They stressed, however, that it must be easy to use. Many aircraft have endured a high rate of disturbance to wiring as a result of modifications and other maintenance actions. There was concern that any intrusive testing could result in a greater number of wiring problems. The following is a summary of comments made by maintenance personnel:

- Relays that are not fully seated cause intermittent problems and a tester is not available to evaluate installed circuit breakers. This can cause drastically reduced mission capability during the troubleshooting process. Over 90% of all respondents stated a need for circuit breaker and electrical panel tester. Circuit breaker panels currently have to be removed to the shop and each breaker tested individually. This process is very time consuming and the introduction of a tester that could check the breakers while installed on the aircraft would drastically reduce the time required during the overhaul/maintenance process.
- Nexus connection points are a source of many wiring problems. Removal of an LRU or troubleshooting one connector requires the disconnection of multiple connectors to access the area of interest. Troubleshooting the original problem can create new failures in surrounding systems.
- Intermittent connections typically could only be found by testing under a load. A continuity test is not sensitive enough to detect a broken wire if both ends of a fractured wire are in contact.
- Wiring faults can take 10 to 15 times longer to troubleshoot than LRU related problems. One reason for this is that the Technical Order usually has the maintainer replace the most probable LRU in order of probability of failure. Wiring is only identified as an area to check as a third or fourth item in the troubleshooting ladder. The result is that wiring may only be examined after the third LRU replacement.
- Approximately 80% of wiring jobs on the aircraft result in total replacement of a harness rather than repairing of particular wiring. This is due to restrictions of Technical Orders on the capabilities of the technician to repair wiring at the field level. Many harnesses have wiring from multiple systems running through them.
- A standard multimeter is the most often used piece of test equipment for testing wiring. It is a very time consuming activity to isolate failures.
- TDR is a technology that would be useful. Past versions, however, were difficult to use and interpret.
- The current method for testing wires for some aircraft involves multiple pieces of test equipment. One facility uses a programmable tester, a multimeter, and a TDR for detecting electrical anomalies in the wiring system. A single piece of test equipment to accomplish the same job would be highly desirable.
- For phase maintenance, the primary method for checking the condition of wires is through visual inspection. This process is very time consuming and inefficient due to the fact that most wires are difficult or impossible to see because of their location within the aircraft or position within a large bundle of wires.

Maintenance personnel of both types of aircraft are very limited in their resources to inspect for wiring problems. Flashlight and mirror inspections identify about one-fourth of all

wiring problems discovered. This approach was not considered proactive. A targeted and specific inspection for particular problems was considered far more productive and beneficial.

It was widely acknowledged by all levels, that the wiring in these aging aircraft is becoming a greater concern each year. The wiring is being subjected to a greater number of intrusive maintenance actions (i.e. grabbing wiring bundles as a handle, rubbing LRUs against wiring during removal and replacement) simply as a result of the aging of other systems within the aircraft. As these systems age and fail in greater numbers, there is a need to disrupt wiring while fixing those systems. It was widely expressed by personnel that a better, more comprehensive approach to wiring inspection must be implemented in the near future.

The multimeter is the primary piece of test equipment that is used by maintainers. The multimeter is hand-held and very practical for using in a flight line environment. Size and ease of use were widely cited by personnel as favorable characteristics of test equipment. The multimeter is limited in its abilities to measure certain aspects of wiring anomalies. Specifically, with the aircraft on the ground, a wire could be hanging by a few strands and pass electrically with the multimeter. That same wire may be cause for failure when the aircraft is in the air or under "load" conditions.

Interviewees widely expressed the need for a wiring analyzer that could potentially narrow down the location of a wiring problem, within such long runs of wire. Typically locating a defect within two inches was desired. Maintainers routinely requested a wiring diagnostic tool that exceeds the capabilities of the multimeter. The ability of a piece of test equipment that could test under "load" conditions was highly desirable. Ease of use, portability and recurring training on the use of the equipment were major considerations for any type of test equipment that may be introduced.

The surveys indicated the majority of wiring problems are found during actual trouble-shooting of a system. A small number of wiring problems were discovered during the phase inspection process during visual inspections. These inspections are very limited and typically are performed with flashlights and mirrors. A vast majority of aircraft wiring is hidden or inaccessible so the rate of discovery using this process is very low.

Conclusions on Maintenance

Current maintenance practices are limited to repair actions and occasional inspection for a fleet wide wiring issue. Typically, wiring inspection is limited to an area under repair. Inspection is primarily visual, with limited use of diagnostic equipment or optical enhancements. Typically, a maintenance action may state "Perform a general visual inspection." Inspection of individual wires, in a bundle or connector, is not a practical technique since handling may introduce new damage. In addition, wiring may also be difficult to inspect in various areas of an aircraft due to inaccessibility (i.e. wiring inside conduits and behind panels or equipment).

Organizations are "living" with the wiring issues. As aircraft age, wiring becomes more difficult to maintain with traditional methods. The current maintenance approach of flying aircraft until an electrical failure is encountered is becoming more difficult to continue. More proactive approaches are needed so that failures can be anticipated and wiring systems can be replaced during scheduled maintenance activities. This can be most efficiently achieved through a program that manages the aircraft wiring system as it ages.

During the aircraft field reviews, there were several common factors noted relating to the wiring system maintenance process. For each aircraft, "phase" inspections are primarily visual. Most wiring problems are actually found through trouble-shooting and not through visual inspection. When troubleshooting is required, the primary instrument is a multimeter. Typically when one wire fault is found, there are additional damaged wires present as well.

For troubleshooting equipment, maintainers wanted tools that are portable and have a setup time less than one hour. Additional capabilities include identifying where a fault is physically located, data recording that can be used for preventive maintenance, and sensitivity to contact resistance in connectors, relays, circuit breakers and splices. In general, field units preferred handheld tools, while depot units preferred comprehensive diagnostic tools.

Functional capabilities:
Hard shorts and opens
Physically locate damage sites
Locate intermittent and degraded interconnections
Store results
Use data collected to enhance wire integrity

In summary, the information collected from the site surveys provided valuable information to be considered in the overall findings of this project. The responses from the questionnaires will be used in helping determine which types of test equipment will best fit the needs of the Air Force aircraft maintenance community. Areas of the aircraft that need to be subjected to more stringent and periodic testing were identified in the survey. The survey indicated a need for a more comprehensive reporting process of wiring maintenance. Data collection is needed to support future decision-making activities concerning aging wiring in the Air Force's aging aircraft inventory.

Analysis of Current Wiring Types Used on Aircraft

What follows is a brief summary of the wire insulation types most commonly found on Air Force aircraft. The most commonly used type of wire appears to still be polyimide, commonly known by its trade name Kapton™ or MIL-W-81381 wire. This wire insulation is used on many commercial and military aircraft. This type of wire is used more often in fighter aircraft due to its lightweight small volume (6 mils) and high temperature capability (200°C). It typically consists of an aromatic polyimide over wrapped to form four layers with a fluoropolymer adhesive and coated with a polyimide lacquer for marking and identification. When new, polyimide exhibits excellent mechanical strength and good abrasion and cut-through resistance. It has a high dielectric strength and high temperature application. It is flame and environmentally resistant. While this insulation has exceptional mechanical properties, when nicked, flexing will propagate the crack to the core conductor. Once cracked, the wiring is vulnerable to arcing or disruption of electrical signals. It is also vulnerable to fluid penetration and exposure to the elements. It is also susceptible to arc propagation if a carbon char forms during an electrical arc event. The stiffness of the insulation can make it difficult to handle. MIL-W-81381 insulation is also susceptible to degradation from high pH (12 and above) cleaners and under certain conditions long-term exposure to moisture (hydrolysis) and ultra-violet radiation

Alternative wire insulation materials include cross-linked Tefzel™ (MIL-W-22759/33-44) which is a cross-linked fluoropolymer. It is higher weight and larger volume than polyimide constructions. It's mechanical properties begin to drop above 70°C specifically cut-through resistance. Additionally, Tefzel™ will generate considerably more smoke than other types of aerospace wiring when burned. There is also an issue with conductor corrosion in silver plated wire (red plague). Another widely used type of insulation in Air Force aircraft is Teflon (MIL-W-22759). Teflon is lightweight, arc tracking resistant, abrasion resistant, and heat resistant. Although, Teflon is known to flow under stress and high temperature, creating non-uniform

thickness. For PVC, Kynar, and other materials such as polyalkene (MIL-W-81044), there are flammability, chafing/environmental resistance and thermal stability issues. One of the more recently available wire insulations is a composite construction containing primarily Teflon with a small percentage of a modified aromatic polyimide (MIL-W-22759/88-). Much of the original development and testing was part of an AFRL sponsored contract in the late 1980's. The polyimide is sandwiched between two Teflon layers. This insulation has a good balance of properties, exhibiting excellent environmental performance while maintaining good mechanical properties over full temperature range, with improved flexibility and excellent arc propagation resistance compared to MIL-W-81381. This has become one of the recommended wire insulation alternatives for aircraft wired with MIL-W-81381.

The objective of the Improvement of Wire System Integrity for Legacy Aircraft Program is to select wire integrity test equipment and methods for use by Air Force maintenance organizations. The desired methods should be simple to use, easy to setup, adaptable to AF maintenance environments, require minimal training for technical school graduates to use and available for fielding during FY02. handheld meters and automated wire analyzers are the two categories of test equipment being considered.

Handheld

Handheld tools are categorized as battery operated, single or multi-function meters approximately the size of handheld multimeter. The readout format can be either digital or analog; however, digital displays are preferred. The desired functions are isolation of conductor shorts and opens, spatial indication of fault, indication of wire insulation degradation, and isolation of intermittent faults. The handheld meter should have a signal output for laboratory evaluation.

Wire Analyzers

These units are computerized circuit analyzer systems with the capability to store wiring architectures, generate and store test programs, conduct bulk and individual conductor testing, store test data, allow data manipulation, and provide analysis and report generation capabilities. The system should be able to test up to 5,000 points and be expandable to 100,000 points. It is desirable to have the handheld meters integrate with the portable systems. Options on the wire analyzers can include resistance, 4 wire Kelvin bridge, DC voltage, AC voltage, and capacitance measurements, voltage and current stimuli capability.

The two leading technologies used in test equipment currently being evaluated involve time domain reflectometry and standing wave reflectometry. Common to these reflectometry methods is the sending of a signal down the wire, which is treated as a transmission line, and sensing the reflected signal.

Time Domain Reflectometry

Time Domain Reflectometry is the analysis of a conductor (wire, cable, or fiber optic) by sending a pulsed signal into the conductor, and then examining the reflection of that pulse. Wiring and insulation anomalies may be precisely located by examining the polarity, amplitude, frequencies, and other electrical signatures of all reflections. Any device or wire attached will cause a detectable anomaly. TDR analysis will usually NOT detect capacitively isolated devices or inductive taps. In the case of capacitively isolated device or inductive tap, the TDR sweep is always supplemented by a detailed high frequency cross talk evaluation and a detailed physical inspection.

TDR use is based on the theory nearly all power and control circuits can be analyzed as radio frequency (RF) transmission line with a load on the end. This allows circuit components to be separated in time and analyzed individually while measurements are made from a remote location. Pulse width and rise time determine the length of line which can be tested using TDR. Wires are not perfect in construction and there will always be some sort of anomalies reflected in the waveform return and/or that the signals will experience loss as a function of time and distance. TDR sends out a square-wave pulse which contains frequencies from DC to 1 GHz that travels down a transmission line at a speed slightly less than the speed of light depending on the type of wire under test. During the travel down the transmission line the current and voltage wave can be measured as a function of time and distance. The resultant current and voltage wave is called the incident traveling wave. The characteristic impedance Zc is seen by a source connected to the transmission line. When a transmission line is terminated with a resistor equal to Zc then the incident traveling wave is absorbed and no waveform is reflected. But if the termination of the transmission line is lesser or greater than Zc then a reflection of the incident wave of the same or opposite polarity is seen. Therefore, when a pulse travels down a wire there will always be a return of X magnitude, given that the line does not terminate with a value equal to that of the original pulse.

Standing Wave Reflectometry

Basically, standing-wave reflectometry (SWR) involves sending a sinusoidal waveform down the wire. A reflected sinusoid is returned from the wire's end, and the two signals add to a standing wave on the line. The peaks and nulls of this standing wave give information on the length and terminating load of the cable. A healthy line's wave pattern will be distinct from that of a line with an open or short circuit.

A microprocessor-controlled oscillator injects a sweep of frequencies into the cable under test and determines whether the discontinuity is caused by a short or an open circuit. Voltage measurements are made before and after the reference resistor. Distance to cable defect is 1/4 of the wavelength injected at the time the impedance approaches zero for an open conductor. Distance to cable defect is 1/2 of the wavelength injected at the time the impedance approaches zero for an shorted conductor. A microprocessor is used to set the sweep frequencies using a numerically controlled oscillator (NCO). In a first pass, test signals are injected from 1 MHz to 50 MHz, in 50 kHz steps. In a second pass, test signals are injected in 4 kHz steps only in the frequency region where the discontinuity was detected.

Lab Evaluation

The objective of the laboratory evaluation is to validate equipment supplier specifications (precision accuracy, sensitivity, repeatability, functionality), determine the maturity of the equipment, and the applicability to the Air Force maintenance environment and finally to provide feedback to the equipment suppliers. Since some of the testers being evaluated are still being modified, the results will be fed back to the developer as suggestions to be incorporated in follow-on designs.

Material and equipment used in this study include a fraying machine which will duplicate common chafing scenarios, a dither (wire bender) used to break internal wires without breaking the insulation, and assorted standard electrical laboratory equipment such as oscilloscopes, multimeters, network analyzers, and an IR camera.

The testing not only verifies equipment specifications for finding the obvious shorts and opens but also tests the sensitivity of the wire analyzer, through varying degrees of insulation, conductor and shield damage. Special cases such as corroded connectors, splices and fraying will

also be looked at. Wires will be aged in environmental chambers and the change in wire test results will be observed. Component testing such as relays and circuit breakers will also occur. The testing approach will be (1) Verify test bed configurations and establish a base line (2) Identification of induced defects and faults in the test bed (3) To determine ease of use using such factors as operator dependence or the amount of training required.

The test set up consists of three test beds. The first is designed to test handheld and wiring analyzers using representative F-16 wires. The second uses both the F-16 representative wires and selected F-16 harnesses. The third will use both new and used F-16 aircraft harnesses. Actual preliminary onboard aircraft testing evaluation and demonstration will be accomplished on an aircraft battle damage repair (ABDR) jet.

Test procedures consist of testing undisturbed and fault induced wire, then recording the results. Items to be considered while the laboratory evaluation is preformed

-Varying distance to fault (potential testing and accuracy/precision measurements)
-Varying degree of the induced faults (conductor,insulation, and shield)
-Format of reports (web-based, digital, and graphical)
-Test duration
-Preparation time, training required and ease of use
-User interface, ease of output interpretation
-Quality of artifacts (reports)
-Technical manuals (user instructions, updates from a remote site)

The testing not only verifies equipment specifications for finding the obvious shorts and opens, but special tests will be conducted to test the sensitivity of the device in identifying varying degrees of insulation, conductor, and shield damage. Special cases such as corroded connectors, splices, and fraying will be examined. Environmental testing to evaluate the effects on wire test results will further test the devices. In the future, component testing will also be accomplished.

Overall summary

The user/test equipment interface is the single biggest problem in automated electrical testing of aircraft. The test equipment needs to be able to display the results in a user-friendly manner. The primary method currently used by maintainers to identify problems is visual inspection. Most wiring problems, however, are found through trouble-shooting, not through visual inspection. Manual (multimeter) electrical testing is very time-consuming. Most troubleshooting is accomplished with a multimeter. Many problems erroneously check okay when tested with a multimeter. To find the problem the connector often has to be demated. Currently, there is no capability to test circuit breakers on the operational side. Maintainers would like a way to test circuit breakers and a method to tell the condition of outer insulation layer and the conductive properties of the wire. Wiring is part of the aircraft infrastructure and needs to be thought of in the same manner. Maintenance organizations are living with the wiring issues, conducting phase inspections visually. Currently, modifications/repairs use large, complex wire test systems and may take days to accomplish. Maintainers want something portable that has enhanced capabilities over current multimeter capabilities. They want it to be easy to use and portable and have a set-up time less than one hour. It should be able to record data that could be used for preventative maintenance. The tester should be able to identify where fault is physically located. It should be able to identify sticking relays and trends in contact resistance. Since many wires pass in a no-load condition yet fail under load, the ability to test a wire under load would be beneficial. Field units favor handheld tools, while depot units favor comprehensive tools. These are the goals this program is intended to address.

Wire integrity evaluation is a very dynamic area of research. New promising areas under development include frequency domain reflectometry (FDR) and impedance spectroscopy. FDR uses sine waves, but it directly measures the phase difference between the incident and reflected waves. Any faults in the wire will generated resonances between the two signals. Researchers at Utah State University with support from Management Sciences Inc, and the Naval Air Systems Command are developing this method. Impedance spectroscopy involves the extraction of electrical parameters from impedance measurements. Using the impedance spectra, you can determine the propagation function, which gives the location of the open/short, resistance function which correlates to conductor health, dielectric function that relates to insulation health. Rockwell Science Center in conjunction with Boeing Aircraft Company is accomplishing this work.

Diagnostic tools currently available are not comprehensive enough for maintaining an adequate wire integrity program. It is hoped the efforts of this program and current research will begin the transition from a reactive (fix when it breaks) to a proactive/prognostic health monitoring maintenance process resulting in extended and predictable failure free operating periods for the air fleet.

Bibliography:

1. Wiring Integrity Analysis of Air Force Weapon Systems, Final report on Delivery Order 64 of the Advanced Manufacturing Technology Feasibility Demonstrations (AMTFD) Program Contract Number F33615-96-D-5101, September 2000

2. "Down to the Wire", Cynthia Furse, Randy Haupt, Utah State University IEEE Spectrum February 2001 Volume 38 Number 2

3. Review of Federal Programs for Wire System Safety, Final Report, November 2000, National Science and Technology Council Committee on Technology, Wire System Safety Interagency Working Group.

4. New Insulation Contructions for Aerospace Wiring Applications, Volume I: Testing and Evaluation, Final Report WL-TR-91-4066, performed by McDonnell Douglas Corporation under contract F33615-89-C-5605 to Wright Laboratories, Wright-Patterson AFB, OH.